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Current Harmonic Mitigation Using D-STATCOM

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Abstract: Increase of rectifiers for converting AC current to DC current can increase current harmonic in grids. These rectifiers can be Diode rectifiers or Thyristor based rectifiers used for variable speed drives or other applications. Then, a filter should be used to reduce these harmonic components. In this project, a Voltage Source Converter (VSC) is used as distributed static var compensation (D-STATCOM) to mitigate current harmonic produced by rectifiers. This Power quality issue is introduced, and its IEEE standard is discussed. Then its source and effect on grid is studied and simulation results are shown. Finally, a VSC D-STATCOM is used for mitigation of current harmonic in power systems.

Keywords: Current Harmonic Mitigation, Power Quality, Rectifier, D-STATCOM, Voltage Source Converter.

1. INTRODUCTION

Nonlinear loads are increased widely in recent years. Among these nonlinear loads power electronic based loads have a huge effect on current and voltage distortion of grid. Some of these loads like motor drives, electric vehicles, air conditioning systems, distributed generation and storage systems, LED lights, computers and laptops, cell phone chargers create power quality issues in distribution systems [1-2].

In DC system, power is generated with DC sources like Photovoltaic systems or converted from AC generators to DC format using a rectifier. AC systems are based on three phase AC grid that a rectifier is used to convert AC current to DC for utilization in DC loads.

Rectifier convert AC current to DC current. They use semiconductor devices like Diode, Thyristor, or IGBTs and MOSFETS. Diode rectifiers do not have control on current but are more reliable and less expensive [3]. However, Thyristor and other active switches has control on current. However, the main problem of these converters is producing of current harmonic. This produced current harmonic of rectifiers can disturb grid current with increasing of motor drives in industry areas and DC loads like battery in electric vehicles.

Harmonics are Periodic disturbance for steady-state condition. It can happen on grid voltage or current that ideally should be sinusoidal. Current harmonic caused by non-linear loads like power electronic rectifiers [4].

Conventionally harmonic filters are used for reducing current harmonic. Harmonic filters are divided to passive filters and active filters. Passive filters have problems as resonance, fixed filter frequency, and tuning issues.

Active filters include static synchronous compensator (STATCOM), active power filter (APF), dynamic voltage regulator (DVR), and unified power quality conditioner (UPQC) [3]. Power electronic converter used on them like in active power filters are voltage source converter (VSC).

Different researcher used STATCOM for reactive var compensation. A complete review of distribution systems voltage sag has been done with DVR and D-STATCOM in [5]. In addition, a DSTATCOM is proposed in [6] and its different control methods are discussed for optimum operation. It used an instantaneous reactive power theory for an adaptive controller. Moreover, a D-STATCOM for load compensation is introduced in weak grid power systems. Each of these methods have their own advantages and disadvantages that depends to their application and operation conditions [7].

In [8], the mathematical modeling of two-level voltage source converters is presented to assess overvoltage and overcurrent transients experienced by the switches under DC and AC fault scenarios and by considering different grounding schemes. For this purpose, the maximum value of switches current and voltage are determined under SLG, DLG, PPG, and NPG fault conditions. The results confirm the significant impact of grounding resistance on the switches currents and voltages under different ground fault conditions.

In [9], an accurate method is proposed to identify an AOV to voltage sag in case of SPG fault occurrence. The voltage sag performance assessed considering the most often used FACTS devices for mitigation of voltage sag in practical applications, STATCOM and TCSC.

In this project an active harmonic filter is used to reduce current harmonic in distribution levels. This is called distributed static var compensation (D-STATCOM) and used to mitigate current harmonic produced by Diode and Thyristor rectifiers. In addition, an unbalance load is used. The structure of this report is as following. First power quality issue is introduced by current harmonic source and power quality disturbance source are studied. Then, indices and characteristics on current harmonic is define. Moreover, standards and guidelines regarding this power quality issue will be discussed.

In addition, impact of current harmonic disturbance will be shown. Also, means for mitigation on current harmonic will be introduces. Finally, a D-STATCOM will be used to reduce the current harmonic and its operation and control will be discussed with a simulation.

2. CURRENT HARMONIC SOURCE

Harmonics source are generally nonlinear loads that can change sinusoidal waveforms to other formats. Fig.1 shows operation of linear load vs nonlinear load. As it is shown linear load with sinusoidal voltage in a stiff grid, has sinusoidal current. However, nonlinear load produces non sinusoidal current from sinusoidal voltage.

Current harmonic sources can be diode or thyristor Rectifier used for Variable Frequency drives, home users, Electric Vehicles, and Electric Trains. 3-phase variable frequency drive is the most common harmonic source which can use diode or Thyristor rectifier. Some of current harmonic sources are shown in Fig.4.

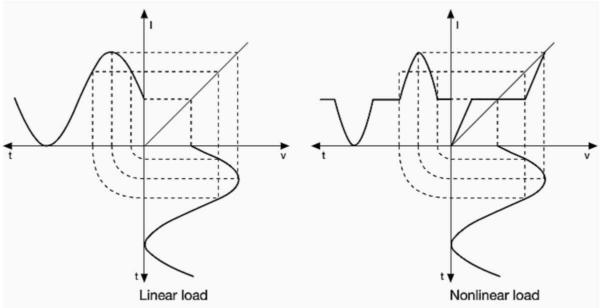

Fig. 1. Linear load waveform and Non-linear load waveform [3].

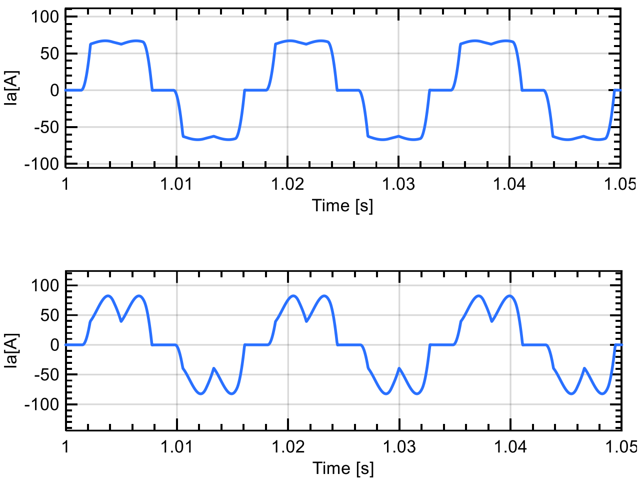

Fig. 2. Different diode rectifier currents.

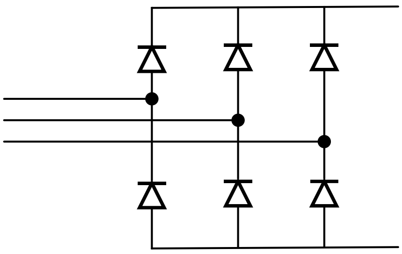

Fig. 3. A diode rectifier current [2].

2.1 Diode Rectifier

Current harmonic produced with nonlinear loads like rectifiers. A diode rectifier circuit with load is shown in Figure 3. This case is when current source inverter is used at motor drive side. In addition, a diode rectifier circuit with capacitor load is shown in Figure 2. This is a case that a voltage source converter is used.

2.2 Thyristor Rectifier

Thyristor rectifier has better control of current and is more efficient, however it needs a controller for fire pulses of thyristors. Due to discontinuous voltage of thyristor rectifier, a capacitor load cannot be used, a Thyristor is shown in Fig. 5. A Thyristor rectifier current is shown in Fig. 6.

3. INDICES & CHARACTERUSTICS

To show effect of current harmonic appropriate indices should be introduced. The indices are essential for current harmonic measurement and evaluation of harmonics. Then remedial actions like harmonic filters can be used to mitigate in case indices are showing more than it standard values. The first and most important indices is Total harmonic distortion (THD):

$$THD_I = \frac{\sqrt{\sum_{h=2}^{H} I_h^2}}{I_1} \tag{1}$$

Next important indices is Individual harmonic distortion (IHD):

$$IHD_I = \frac{I_h}{I_1} \tag{2}$$

In addition, one of most important indices is Total demand distortion (TDD):

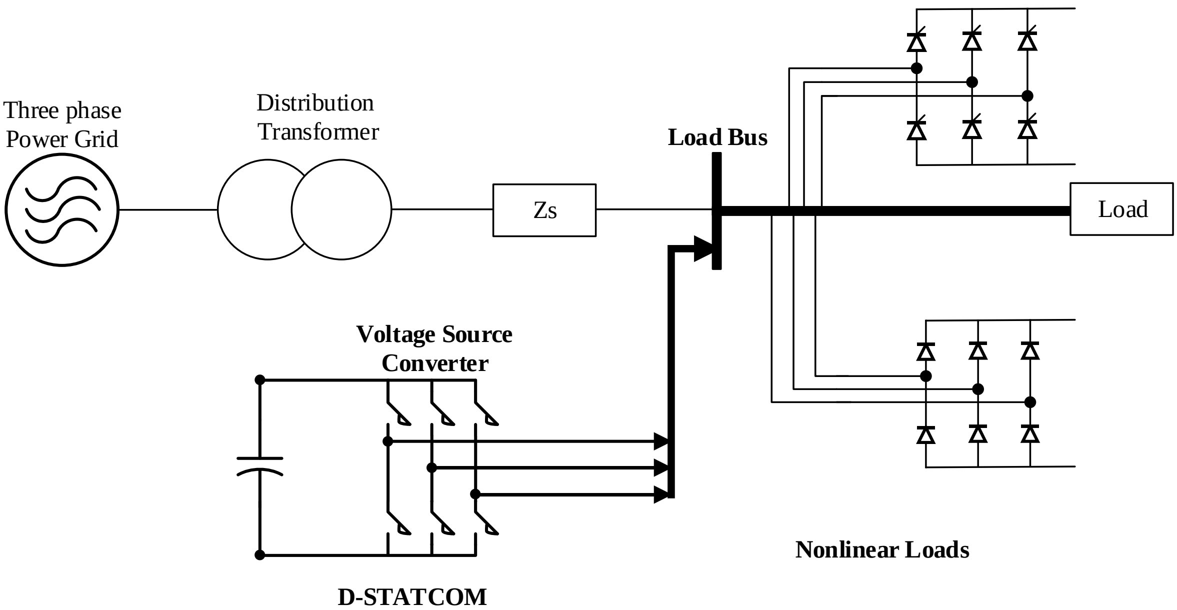

Fig. 4. Current harmonic sources.

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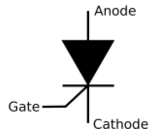

Fig. 5. Thyristor.

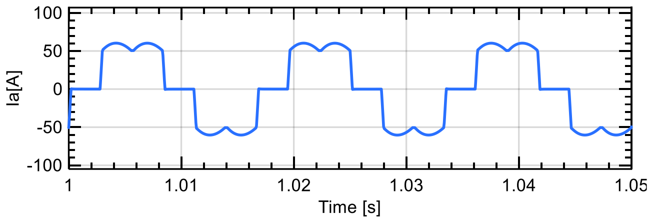

Fig. 6. Thyristor rectifier current.

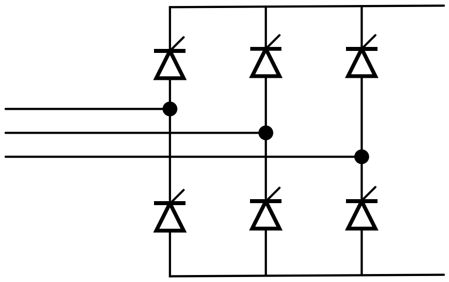

Fig. 7. A thyristor rectifier circuit II.

$$TDD_I = \frac{\sqrt{\sum_{h=2}^{H} I_h^2}}{I_L} \quad (3)$$

TDD compare to THD includes current rating of device and gives better understanding of harmonics.

4. STANDARDS

Like any other evaluation a base value should be used for comparison and evaluation. For current harmonic IEEE Standard 519 is used which is define by Institute of Electrical and Electronics Engineers (IEEE). This standard is IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems first introduced in 1981 and then revised in 1992 and 2014. Its Focus is on Harmonic measurements and Recommended harmonic limits for voltage and current distortion.

Table 1: Voltage Distortion limits

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \le 1.0$ kV	5.0	8.0
1 kV < $V \le 69$ kV	3.0	5.0
69 kV < $V \le 161$ kV	1.5	2.5
161 kV < V	1.0	1.5[a]

Table 2: Current Distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

4.1 Harmonic Voltage Limits

Harmonic Voltage Limits for power system is define based on its voltage level. For harmonic voltage limits utilities company are responsible at point of power coupling (PCC). Harmonic voltage limits for 120V to <69kV are shown in Table 1[].

4.2 Current Distortion Limits

The other standard factor is Current Distortion Limits. For current limit users are responsible at PCC point to keep current harmonic limit at its value.

Current harmonic limits for voltage levels of 120V to <69kV are shown in Table 2. In addition, current Distortion Limits for voltage levels greater than 161kV are shown in Table 3.

4.3 Harmonic Measurement

Another important consideration is harmonic measurements. Harmonic measurement should be accurate for appropriate operation in power system. According to IEEE 519 standard any instrument used should comply with the specifications of IEC 61000-4-7 and IEC 61000-4-30 standards.

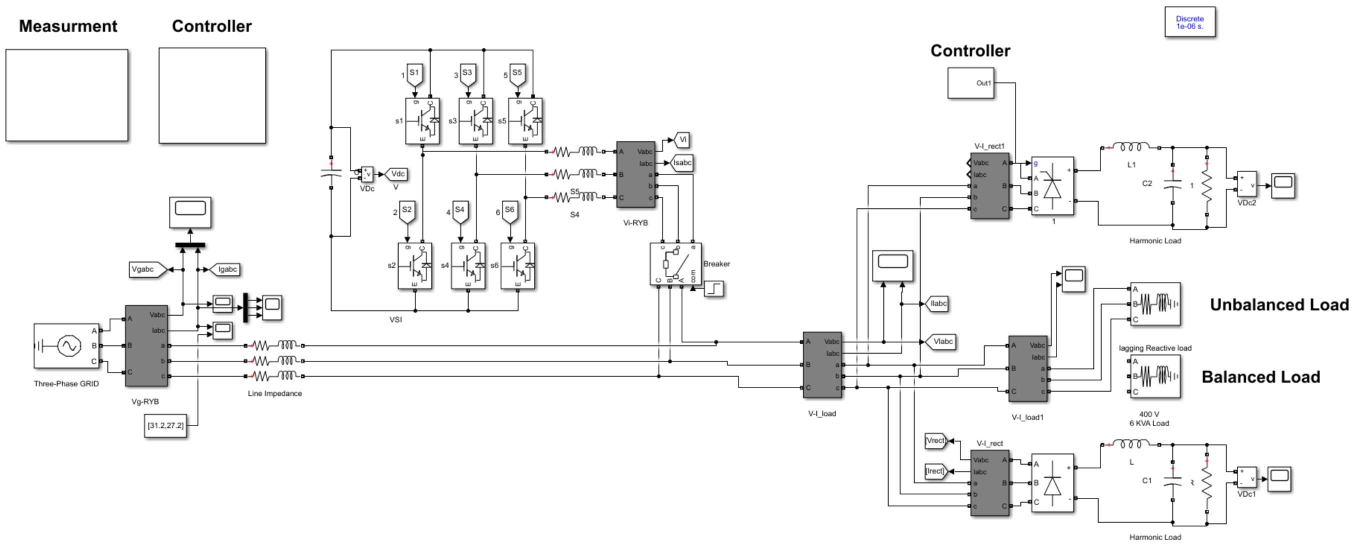

Fig. 8. Simulation.

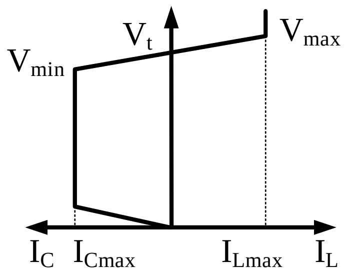

Fig. 8. STATCOM V-I characteristics.

Table 3: Current Distortion limits for systems rated greater that 161 Kv.

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{sc}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
$< 25^c$	1.0	0.5	0.38	0.15	0.1	1.5
25 < 50	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

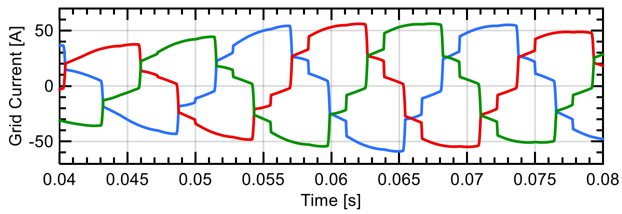

Fig. 10. Grid current before suing D-STATCOM.

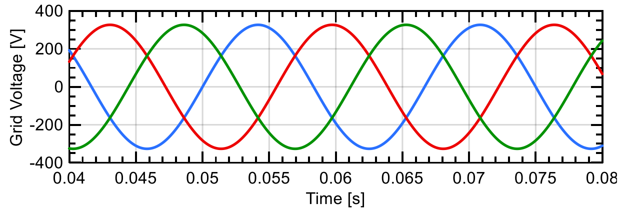

Fig. 11. Grid voltage before suing D-STATCOM.

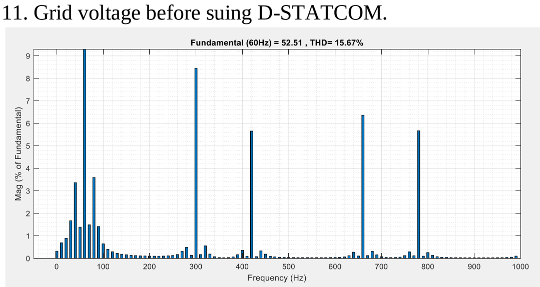

Fig. 12. Current FFT before suing D-STATCOM.

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 30 Hz              1.67%   190.8°
 40 Hz              3.36%    71.7°
 50 Hz              1.39%     7.0°
 60 Hz  (Fnd):    100.00%   -20.0°
 70 Hz              1.49%   -60.8°
 80 Hz              3.59%   235.8°
 90 Hz              1.42%   126.7°
100 Hz              0.65%   103.5°
110 Hz              0.40%    88.7°
120 Hz  (h2):       0.29%    76.8°
130 Hz              0.23%    66.5°
140 Hz              0.19%    57.2°
150 Hz              0.16%    48.4°
160 Hz              0.14%    40.0°
170 Hz              0.12%    32.0°
180 Hz  (h3):       0.11%    25.1°
190 Hz              0.11%    16.0°
200 Hz              0.10%     7.9°
210 Hz              0.10%    -0.4°
220 Hz              0.10%    -9.3°
230 Hz              0.10%   -18.4°
240 Hz  (h4):       0.11%   -29.0°
250 Hz              0.13%   -41.7°
260 Hz              0.17%   -58.8°
270 Hz              0.31%   269.3°
280 Hz              0.49%   137.9°
290 Hz              0.14%    77.1°
300 Hz  (h5):       8.45%   147.6°
310 Hz              0.17%     4.7°
320 Hz              0.56%   -61.2°
330 Hz              0.19%   176.1°
340 Hz              0.07%   162.7°
```

Fig. 13. Current IHD before suing D-STATCOM

5. EFFECT OF CURRENT HARMONICS

The goal of power systems is to transfer electrical energy from generators to end users. Then, electric current and voltages should be sinusoidal, and any disturbance can change their shape. Non sinusoidal waveforms will have harmonics that can have undesired effect on power systems. For example, Harmonics in power systems result in

- ✓ Increased heating in the equipment and conductors
- ✓ Cable Insulation Breakdown
- ✓ Misfiring in variable speed drives and Motor failure
- ✓ Transformer failure
- ✓ Capacitor bank failure
- ✓ Resonance
- ✓ Circuit breaker tripping [10-14]

6. D-STATCOM

Flexible AC transmission systems (FACT) compensate reactive power [3] and improves voltage profile and currents waveform. It can include series or shunt methods or a combination of both. It includes Static Var Compensator (SVC), Thyristor-Controlled Series Capacitor (TCSC), Static Synchronous Compensator (STATCOM), and Unified Power Flow Controller (UPFC). Among them STATCOM has these advantageous:

- Better characteristics
- Faster response
- Constant current characteristics
- Controllable Voltage source
- Smaller in size

However, STATCOM also has these disadvantageous:

- Higher losses
- Higher Cost [14-18]

Voltage current characteristic of STACOM is shown in Fig. 4. Its V-I curves are shown in Fig.8. As it is shown, STATCOM can operate at full current range from 0.2 p.u. So, the rating of power system current cannot limit STATCOM for producing capacitive or inductive current and does not depend on AC voltage system. Then, for medium and low voltage systems like distribution levels distribution STATCOM(D-STATCOM) is introduced to improve current and waveform characteristics of electric system.

7. SIMULATION

In this project MATLAB/Simulink tool is used for system simulation. The simulated system is shown in Fig. 9. It includes a three-phase system that is operate as infinite bus with stiff voltage. Then, it is connected to loads and consumers through a line impedance. Loads include a diode and thyristor rectifiers and an unbalance load. These work as nonlinear and unbalance loads that disturb grid current and inject harmonics. Then, to improve the current waveform a D-STATCOM is connected at PCC to compensate current waveform though a breaker.

7.1 Before using D-STATCOM

Current and voltage waveforms are shown in Fig. 10 and 11 before connecting D-STATCOM. As shown current waveform has harmonic and is not sinusoidal. However, grid voltage is sinusoidal.

In addition, Fast Fourier Transformation (FFT) tool of MATLAB/Simulink is used to evaluate current THD. The FFT results are shown in Fig. 12. As it is shown, current THD is 15.67% in this situation that is more that IEEE 519 standard limits.

Moreover, Individual harmonic distortion (IHD) are shown in Fig. 13. As it can be seen, 5th order harmonic is the highest

harmonic component. Also, 5th order Individual harmonic distortion is 8.45% that is more that IEEE 519 standard limits.

7.2 Using D-STATCOM

To mitigate current harmonic a D-STATCOM is used. Control of D-STATCOM is very important and has several stages. First a Clark Transformation is used to convert abc to dq0. dq0 are constant and using them for proportional integral (PI) controller is more effective. Then, a Phase Locked Loop (PLL) is used for grid synchronization. More importantly, Current controller using PI controller will be used. These controllers have feedforward part and decoupling part. In addition, a DC link Voltage control is used with a PI controller. Finally, inverse dq0 to abc transformer is used and generated reference signal will be used in sinusoidal modulation.

8. CLARK TRANSFORMATION

Clark Transformation transfer abc component to direct quadratic(dq0) components. Formula for abc to dq0 transformation is:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ -\sin(\omega t) & -\sin(\omega t - \frac{2\pi}{3}) & -\sin(\omega t + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{4}$$

This transformation needs angle of power system grid. Then a Phase Locked Loop (PLL) is used to obtaining information of grid angle. It is also using for grid synchronization. Then PLL obtains grid angle from grid voltage measurement as shown in Fig. 15. Also, abc/dq0 transformation measured convert grid voltage, load current, and D-STATCOM current to dq0 components. Grid current controller of D-STATCOM is shown in Fig. 14. It first calculates grid current from load current using a low pass filter. Then it controls DC link current using a PI controller. Then, control output current of D-STATCOM using two PI controller. Each PI controller includes a feedforward from grid voltage and an decoupling component to separate each controllers operation. These controllers are tuned based on observation of PI errors and try and error. And at the end each signal will transfer from dq0 to abc using a dq0/abc transformation. These signals are

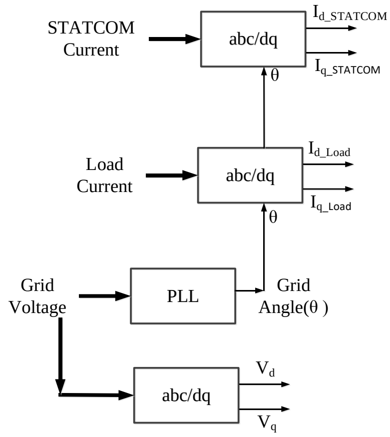

Fig. 15. PLL and abc/dq0 transformations.

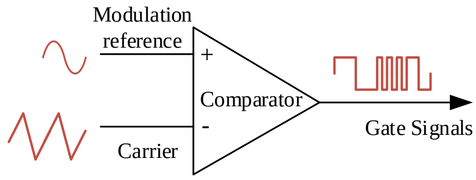

Fig. 16. Sinusoidal modulation.

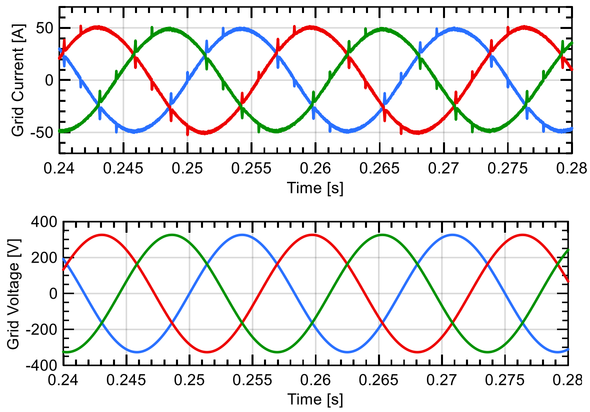

Fig. 18. Grid voltage after suing D-STATCOM.

reference signals that feed to modulation block.

9. MODULATION METHOD

Modulation is used to transfer reference signals to logic signals for gate pulses. Different modulations can be used include Sinusoidal modulation, space vector modulation, hysteresis modulation, harmonic elimination modulation, and

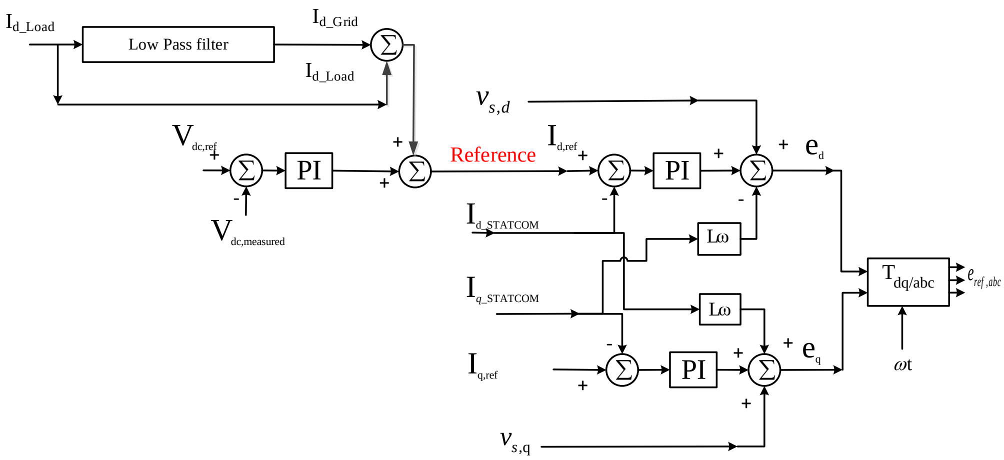

Fig. 14. A thyristor rectifier circuit II.

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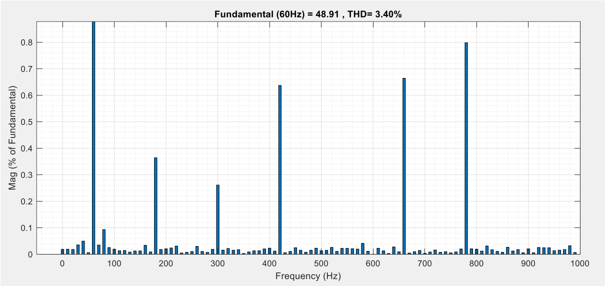


FiG. 19. Current FFT after suing D-STATCOM.

40 Hz		0.05%	7.6°
50 Hz		0.01%	193.4°
60 Hz	(Fnd):	100.00%	-0.9°
70 Hz		0.03%	17.5°
80 Hz		0.09%	19.5°
90 Hz		0.03%	-46.1°
100 Hz		0.02%	-49.2°
110 Hz		0.01%	-56.8°
120 Hz	(h2):	0.01%	50.2°
130 Hz		0.01%	204.7°
140 Hz		0.01%	-48.1°
150 Hz		0.01%	-40.5°
160 Hz		0.03%	203.5°
170 Hz		0.01%	-19.0°
180 Hz	(h3):	0.36%	10.1°
190 Hz		0.02%	258.7°
200 Hz		0.02%	-41.7°
210 Hz		0.02%	237.0°
220 Hz		0.03%	73.8°
230 Hz		0.00%	37.0°
240 Hz	(h4):	0.01%	101.2°
250 Hz		0.01%	-52.1°
260 Hz		0.03%	247.5°
270 Hz		0.01%	262.3°
280 Hz		0.01%	-8.7°
290 Hz		0.02%	-87.1°
300 Hz	(h5):	0.26%	-66.2°
310 Hz		[illegible]	[illegible]
320 Hz		0.02%	8.7°
330 Hz		0.02%	208.7°
340 Hz		0.02%	123.5°
350 Hz		0.00%	-50.1°

Fig. 20. Current IHD before suing D-STATCOM.

340 Hz		0.02%	123.5°
350 Hz		0.00%	-50.1°
360 Hz	(h6):	0.01%	16.2°
370 Hz		0.01%	54.0°
380 Hz		0.01%	140.6°
390 Hz		0.02%	195.2°
400 Hz		0.02%	152.9°
410 Hz		0.01%	-14.6°
420 Hz	(h7):	0.64%	248.6°
430 Hz		[illegible]	[illegible]
440 Hz		0.01%	-27.7°
450 Hz		0.02%	133.8°
460 Hz		0.01%	134.7°
470 Hz		0.01%	17.9°
480 Hz	(h8):	0.02%	265.2°
490 Hz		0.02%	36.5°
500 Hz		0.01%	135.8°
510 Hz		0.01%	-80.4°
520 Hz		0.03%	167.9°
530 Hz		0.01%	30.2°
540 Hz	(h9):	0.02%	267.7°
550 Hz		0.02%	214.1°
560 Hz		0.02%	241.0°
570 Hz		0.02%	80.5°
580 Hz		0.04%	223.8°
590 Hz		0.01%	34.1°
600 Hz	(h10):	0.00%	193.5°
610 Hz		0.02%	155.8°
620 Hz		0.01%	110.6°
630 Hz		0.00%	183.4°
640 Hz		0.03%	0.8°
650 Hz		0.01%	112.9°

Fig. 21. Current IHD uSing D-STATCOM.

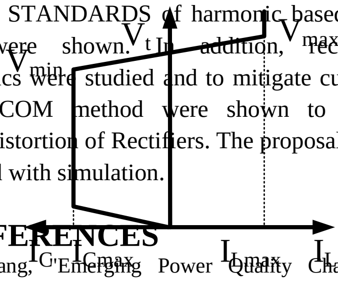
so on. In this project Sinusoidal modulation is used.

In Sinusoidal modulation Carrier waveforms are Triangular waveforms which compared with reference waveforms and Gate signals will be generated as shown in Fig. 16. As shown in Fig. 19, after using this D-STATCOM Current THD is reduced to 3.4% that is below 5%. Then D-STATCOM could perform efficiently to mitigate current harmonic.

In addition, 5th order Individual harmonic distortion that was highest harmonic distortion is also reduced to 0.26% as shown in Fig. 20. Moreover, based on Fig. 21 that shown FFT analysis of current harmonic, 7th order harmonic become the dominant harmonic component in current.

10. CONCLUSION

In this report, current harmonic mitigation have been discussed. First Current Harmonic distortion sources specifically rectifiers and unbalance loads were studied. Then Indices and STANDARDS of harmonic based on IEEE 519 standard were shown. In addition, rectifiers current characteristics were studied and to mitigate current harmonic a D-STATCOM method were shown to solve Current Harmonic distortion of Rectifiers. The proposal D STATCOM was verified with simulation.



11. REFERENCES

[1] X. Liang, "Emerging Power Quality Challenges Due to Integration of Renewable Energy Sources," in IEEE Transactions on Industry Applications, vol. 53, no. 2, pp. 855-866, March-April 2017.

[2] Fang Zheng Peng and Jih-Sheng Lai, "Dynamic performance and control of a static VAr generator using cascade multilevel inverters" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 33, NO. 3, MAY/JUNE 1997

[3] K.R. Padiyar, FACTS Controllers in Power Transmission and Distribution, NewAge International Publishers, India, 2008.

[4] M. S. El-Moursi and A. M. Sharaf, "Novel controllers for the 48-pulse VSC STATCOM and SSSC for voltage regulation and reactive power compensation," in IEEE Transactions on Power Systems, vol. 20, no. 4, pp. 1985-1997, Nov. 2005.

[5] M. H. Haque, "Compensation of distribution system voltage sag by DVR and D-STATCOM," *2001 IEEE Porto Power Tech Proceedings (Cat. No.01EX502)*, Porto, Portugal, 2001, pp. 5 pp. vol.1-.

[6] B. Singh and J. Solanki, "A Comparison of Control Algorithms for DSTATCOM," in *IEEE Transactions on Industrial Electronics*, vol. 56, no. 7, pp. 2738-2745, July 2009.

[7] A. Ghosh and G. Ledwich, "Load compensating DSTATCOM in weak AC systems," in *IEEE Transactions on Power Delivery*, vol. 18, no. 4, pp. 1302-1309, Oct. 2003.

[8] M. Naghizadeh, H. S. Gohari, H. Hojabri, and E. Muljadi, "New Single–Phase Three-Wire Interlinking Converter and Hybrid AC/LVDC Microgrid," *IEEE Trans. Power Electron.*, vol. 38, no. 4, pp. 4451–4463, Apr. 2023.

[9] S. Shakeri, M. Naghizadeh, and S. Esmaeili, "Identifying the Voltage Sags Vulnerability Area with Considering FACTS Devices," in 2020 28th Iranian Conference on Electrical Engineering (ICEE), Aug. 2020, pp. 1–5.

[10] Ruhani, B., Andani, M. T., Abed, A. M., Sina, N., Smaisim, G. F., Hadrawi, S. K., & Toghraie, D. (2022). Statistical modeling and investigation of thermal characteristics of a new nanofluid containing cerium oxide powder. *Heliyon*, *8*(11), e11373.

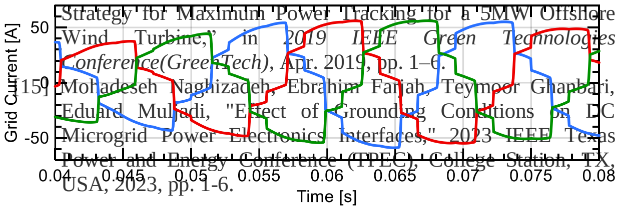
[11] M. Naghizadeh, E. Farjah, H. Samet, and T. Ghanbari, "Fault Tolerability of Power Electronic Interfaces, Impact of Grounding Architecture," in *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, Jun. 2018, pp. 1–6.

[12] O. Mirzapour, F. Mohammadi, and M. Sahraei-Ardakani, "Multidimensional Scenario Selection for Power Systems with

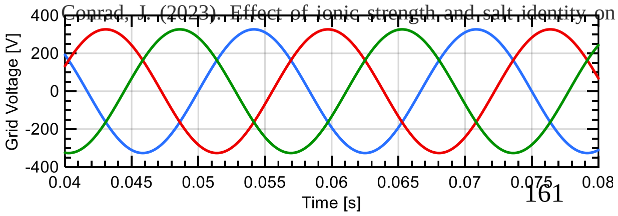
Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{sc}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 25[c]	1.0	0.5	0.38	0.15	0.1	1.5
25 < 50	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

[14] S. Ameli, M. J. Morshed, and A. Fekih, "Baseline Control Strategy for Maximum Power Tracking for a 5MW Offshore Wind Turbine," in *2019 IEEE Green Technologies Conference(GreenTech)*, Apr. 2019, pp. 1–6.

[15] Mohadeseh Naghizadeh, Ebrahim Farjah, Teymoor Ghanbari, Eduard Muljadi, "Effect of Grounding Conditions on DC Microgrid Power Electronics Interfaces," 2023 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, USA, 2023, pp. 1-6.



[16] Safi Samghabadi, F., Ramezani Bajgiran, S., Marciel, A., & Conrad, J. (2023). Effect of ionic strength and salt identity on



swelling behavior of weak polybasic brushes with various charge fractions. *Bulletin of the American Physical Society*.

[17] M. Naghizadeh, E. Farjah, and T. Ghanbari, "DC Microgrid Grounding Impact on Power Electronic Interfaces in Fault Condition," *IEEE Trans. Ind. Electron.*, vol. 67, no. 5, pp. 4120–4132, May 2020.

[18] Roshan, S., Taherian, M., Allahbakhshi, M., & Fariah, E. (2018, May). Improvement of Pulse Power Generators Based on Buck Boost Converter. In *Electrical Engineering (ICEE), Iranian Conference on* (pp. 1275-1279). IEEE.